Synthesis of new heavy nuclei using RNBs

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In proposing new radioactive beam facilities, such as the RIA facility, the issue arises as to the potential for synthesizing new heavy nuclei using radioactive nuclear beams (RNBs). While it is tempting to write several interesting possibilities, we believe that one must make quantitative estimates of the realistic probability of such studies. Accordingly, we have quantitatively evaluated the possibilities of synthesizing heavy nuclei using the proposed RIA facility.

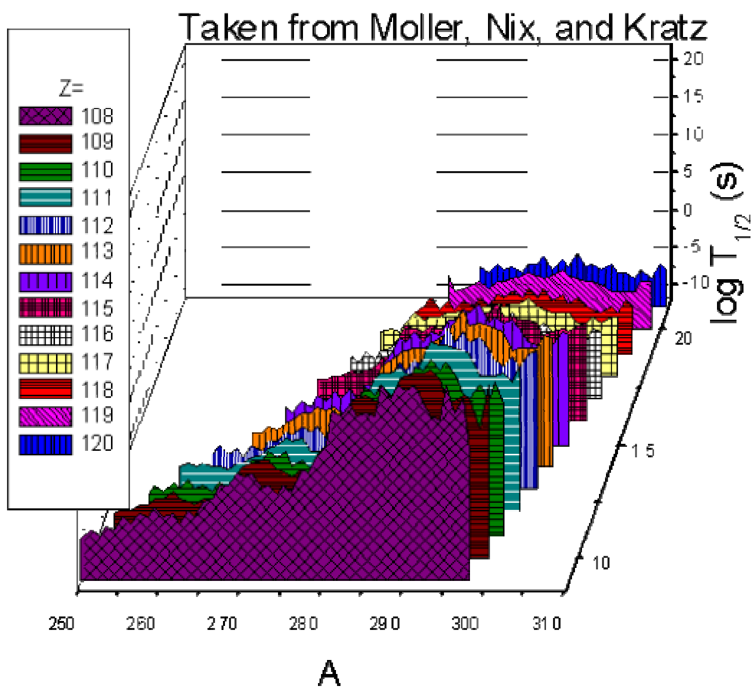

Figure 1. Variation of calculated [1] half-lives of heavy nuclei with Z and A.

We begin by noting the potential value of n-rich beams in synthesizing heavy nuclei (Figure 1). In Figure 1, we show a plot of the calculated half-lives [1] of the heavy nuclei sorted by Z and A. Note that in addition to the expected increases in half-life at the magic numbers N=162 and N=184, one sees a general overall increase in half-life with increasing neutron number. This increase amounts to an increase of orders of magnitude in half-life, that could qualitatively change the character of the studies of the atomic physics and chemistry of these elements. We would also expect that the lowered fusion barriers for the n-rich projectiles might lead to lower excitation energies and greater survival probabilities.

What we have done to examine the possibilities of synthesis of new nuclei using the RIA facility is to do a brute force calculation. We have taken the RIA beam list [2] that gives the identity and intensity of all the expected RNBs that have suitable energies (<15 A MeV) and considered all possible combinations of these projectile nuclei with all "stable" target nuclei (including radioactive actinide nuclei) with appropriate target thicknesses (~0.5 mg/cm^2). All reactions are assumed to take place at a projectile energy equivalent to the Bass barrier [3]. The fusion probability is calculated using a semi-empirical formalism developed by Armbruster[4] that considers fusion hindrance and assumes fusion to be primarily an s-wave process. Γ_n/Γ_f values used to evaluate the survival probabilities are taken from our semi-empirical systematics of Γ_n/Γ_f [5]. For the most promising cases, the fusion probability was re-calculated using the HIVAP computer code [6]. The yield of each projectile-target combination was evaluated in atoms/day.

This formalism was checked by calculating the cross sections of the formation reactions used to synthesize elements 104-112 and comparing them to the observed cross sections. The results (Figure 2) show an agreement between predicted and observed cross sections within an order of magnitude for cross sections ranging over seven orders of magnitude.

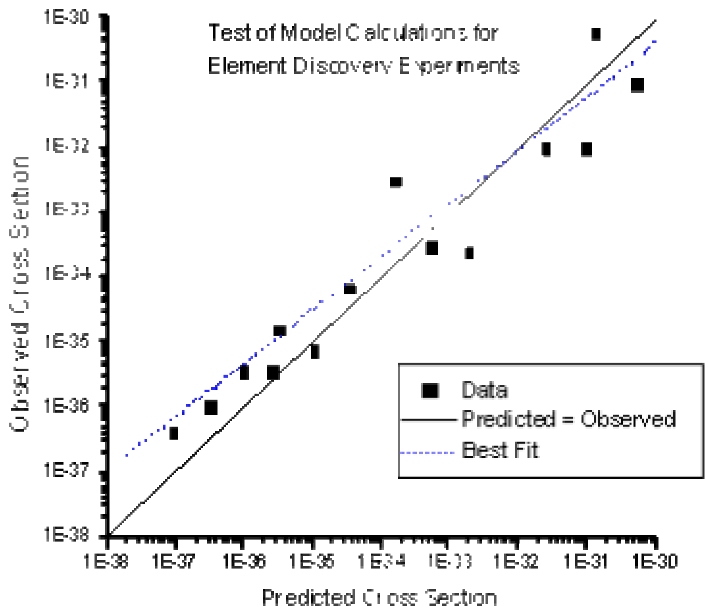

Figure 2. Comparison of observed and calculated formation cross sections for elements 104-112.

The RIA facility appears to offer significant opportunities for the study of the atomic physics and chemistry of the heaviest elements (Figure 3). It appears possible to synthesize significant numbers of very n-rich isotopes of elements 104-108 (Rf-Hs). Because these nuclei have very long half-lives, qualitatively different studies of these nuclei should be possible. These hot fusion reactions typically involve radioactive nuclei that are not far from stability. This is due to the higher fluxes of these nuclei compared to the more exotic projectiles.

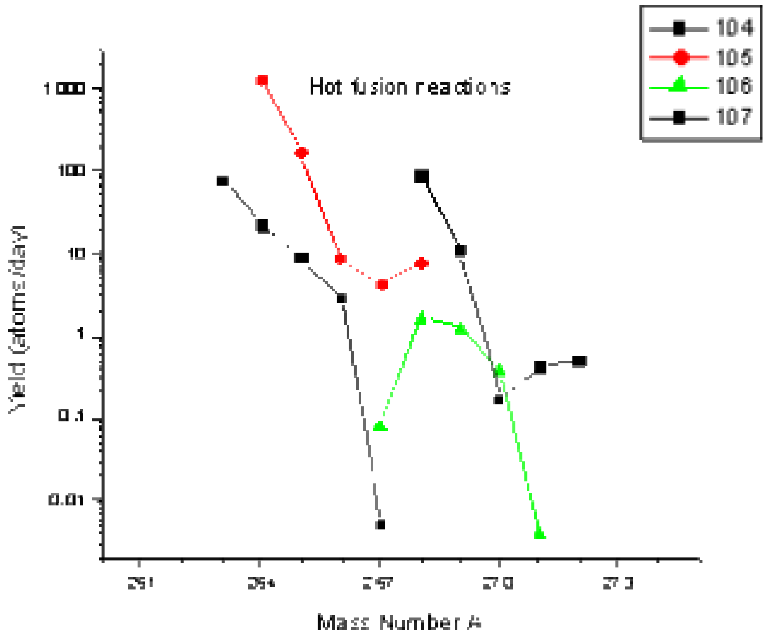

Figure 3. Production rates of n-rich isotopes of elements 104-108 using the RIA facility.

The situation regarding the synthesis of new heavy elements is mixed (Figure 4). While it is possible to make new elements using radioactive beams, the use of stable beams gives higher production rates. (In the stable beam calculations, we have assumed 0.3 pWa beam currents.)

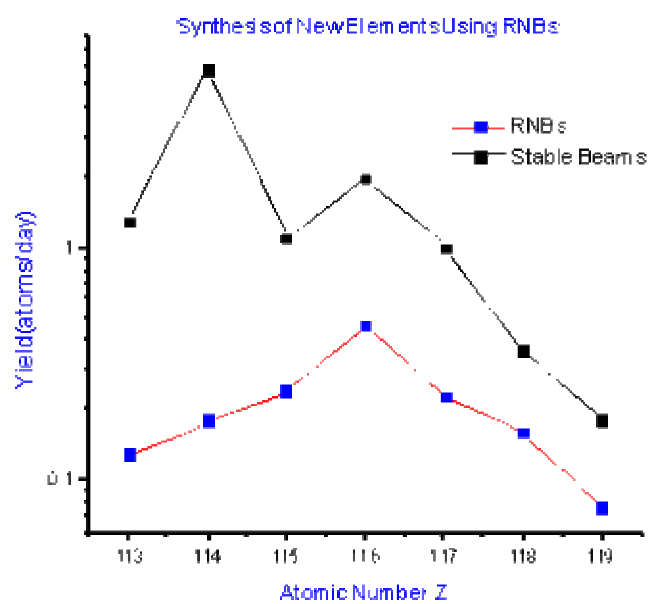

Figure 4. Production rates of new elements using radioactive beams from RIA and stable beams.

The radioactive projectiles lead to more n-rich nuclei than the stable projectiles (Figure 5) which may be important for the study of the nuclear structure of the heaviest elements. One might inquire why the conventional cold fusion reactions do not play a more important role in these simulations. The product of the cross section and available flux is not sufficient to give suitable production rates.

It should be noted that these estimates of production rates do not include any fusion enhancement effects, other than the lowering of the fusion barriers (and excitation energy) with the n-rich projectiles. This is based upon the experimental studies of fusion with n-rich radioactive beams [9,10].

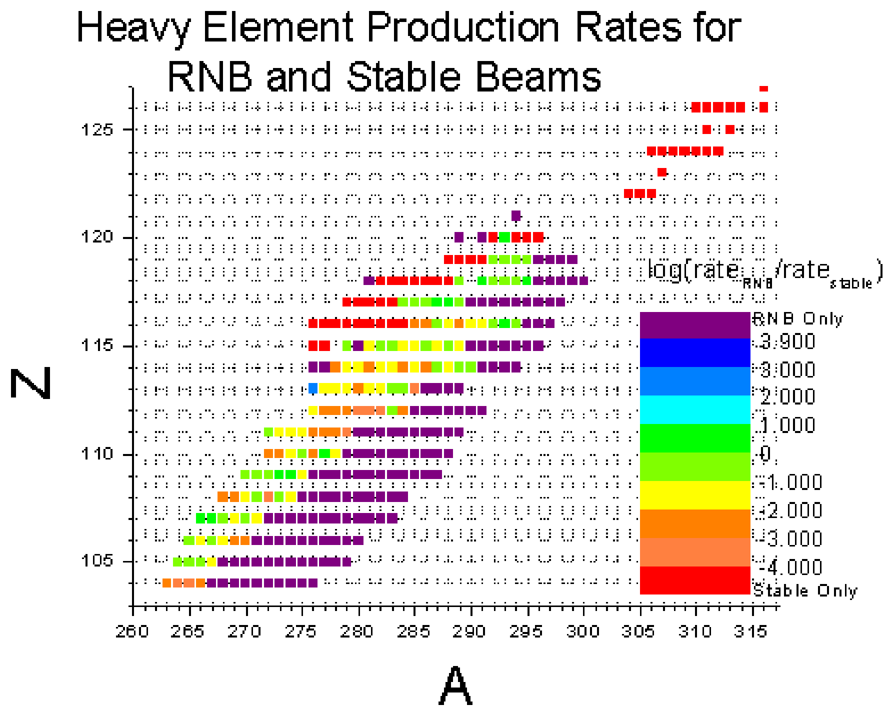

Figure 5. Comparison of production of heavy nuclei with RIA beams and stable beams.

References

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